X64 10834

Technical Memorandum No. 33-52 (Part 2)

An All-Solid-Propellant Nova Injection Vehicle System for the Direct-Ascent Man-on-Moon Project

CLASSIFICATION CHANGE

TO - UNCLASSIFIED

By authority of _____ E.O. 11652

Changed by L. Shirley   Date 10-31-73

"Available to U.S. Government Agencies and
U. S. Government Contractors Only"

jpl
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

January 24, 1962

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
(NASA CONTRACT NO. NAS 7-100)

Technical Memorandum No. 33-52 (Part 2)

t: An All-Solid-Propellant Nova Injection Vehicle System for the Direct-Ascent Man-on-Moon Project. ~~≡~~

1

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

January 24, 1962

CONTENTS

TABLES

FIGURES

PREFACE

This report is Part 2 of JPL Technical Memorandum No. 33-52, which presented studies on (1) a lunar rendezvous technique and (2) the all-solid *Nova* method for performing the manned lunar landing mission. The solid *Nova* content of the original report is presented unchanged here, except that material pertaining specifically to the lunar rendezvous has been deleted from the Preface and from the Summary and Conclusions.

In undertaking a program directed toward a manned landing on the surface of the Moon and return to the Earth, it is necessary that the National Aeronautics and Space Administration (NASA) evaluate the possible system concepts for the mission in order that the most promising system, or systems, can be selected and that the corresponding launching-vehicle and spacecraft developments can be initiated in sufficient time. Two system concepts have received the greatest attention in the preliminary investigations conducted by NASA: (1) the use of a very large liquid-propellant multistage rocket (*Nova*) which carries out the entire mission in a single operation; (2) the use of somewhat smaller liquid-propellant rockets (the *Saturn*) which carry out the missions by rendezvous in a near-Earth orbit and the ensuing assembly and/or refueling operations in the free-space environment. Many alternative system concepts can be devised.

In response to an invitation from NASA, a preliminary design study of an alternate system concept of the manned lunar-landing and return mission has been prepared—the use of solid-propellant rockets in launching-vehicle systems. This concept is, of course, closely related to one of the two which have, up to this time, received primary emphasis. The variation in concept, however, has many inherently desirable characteristics which require evaluation prior to the time a definite development plan is formulated for the manned lunar-landing mission. It is concluded that the solid propellant offers a most favorable approach to the very large vehicle development in terms of development cost and time.

This system study is not presented as a specific proposal recommended for implementation, but rather as a preliminary study of a

PREFACE (Cont'd)

system having particularly favorable characteristics which, it is suggested, should be considered by NASA in the over-all evaluation of the system, or systems, chosen for final development.

In reviewing the schedule and cost information presented in this report, it must be remembered that the study does not encompass the entire gamut of activities that must be integrated for the complete mission accomplishment. The cost estimates cover the needs of the contractors carrying out the portions of the over-all project treated in the study. The estimates do not include the general governmental administrative overhead, the Air Force range costs at Cape Canaveral or the NASA world-wide tracking and communications costs. It assumes that the *Apollo* spacecraft developments are proceeding on a schedule which fits into the system being studied. The study does not include cost estimates for the extensive flight-test program, using *Saturn C-1* and smaller vehicles, which is required for the spacecraft development prior to entering the *Nova* flight phase. The cost estimates for those portions of the *Apollo* spacecraft development that are included in this study are taken from the current NASA Headquarters program reviews. No attempt has been made to evaluate or to duplicate these estimates.

The schedule for the solid-propellant *Nova* system was estimated as an independent system, although the possibility is noted that the spacecraft-development schedule might become the pacing item.

I. A SOLID-PROPELLANT NOVA INJECTION VEHICLE SYSTEM

A. Introduction

With Man-on-the-Moon a major program objective, NASA now has under consideration large solid-propellant boosters as one potential launch method for accomplishing the *Nova* mission as a single operation. While the Jet Propulsion Laboratory is not assigned the responsibility for launching-vehicle development programs, it is felt that the Laboratory's extensive solid-propellant technology and vehicle system experience places it under obligation to submit any pertinent information that might expedite the manned lunar program or enhance the likelihood of its success.

Consequently, the Laboratory has undertaken a preliminary study[1] to answer several basic questions:

1. Is a solid-propellant *Nova* vehicle technically feasible?

2. If so, what might such a vehicle system consist of conceptually?

3. When can the vehicle be made available for a manned lunar mission?

4. What is the approximate cost of the program?

5. What are the major problem areas?

1. Background and Philosophy

The following assumption is considered fundamental:

Within the shortest possible time, NASA must send a man to the Moon and return him safely to Earth.

This may well imply that some type of parallel approach to putting a man on the Moon must be adopted in order to ensure early success. President Kennedy, in his recent address to Congress, did indeed call for both a liquid- and a solid-propellant booster approach for the *Nova* Moon mission. In such a costly parallel effort it appears judicious to avoid the use of any vehicle subsystem as a common element in both vehicles if there is a strong possibility that a delay in the program could arise from that common subsystem. If the liquid-propellant *Nova* schedule were to experience a delay, it might well arise from our limited liquid hydrogen technology and/or the cluster of 200K liquid hydrogen–liquid oxygen J-2 engines. One must conclude, therefore, that the solid-

propellant *Nova* should, for now, use solid-propellant rockets throughout or, alternately, use solid-propellant rockets with relatively small, storable, liquid-propulsion systems which can be based on a more highly developed technology.

If the development of an all-solid-propellant vehicle is to be consistent with the above fundamental assumption, full advantage must be taken of our past experience and present knowledge. It should be recognized that development work on increasing the performance of chemical rocket systems is rapidly approaching a practical upper limit for large systems in which the development cost can be amortized over a very limited production run only. By minimizing a development program, both money and time can be saved. Therefore, a conservative vehicle design incorporating today's state-of-the-art has been adopted for this study.

For a given payload these constraints produce a larger vehicle, but it is believed that the larger size introduces relatively minor problems compared to those arising from a lighter-weight vehicle with a much more advanced design. In addition, it is believed that the more conservative vehicle provides, inherently, a man-rated system at a much earlier point in the flight program and at a reduced cost.

Past experience also indicates that the program should capitalize on rocket motor scaling principles. This powerful tool of scaling was demonstrated to be applicable to solid-propellant rockets in the *Sergeant* Program, when a flight-weight scale model of the nozzle, chamber, and propellant charge accurately predicted the performance and characteristics of the full-scale, flight-weight motor, a unit which weighed 125 times as much as the model. *Pershing, Polaris,* and *Minuteman* have extended in size the applicability of the principle. When this scaling ability is coupled with the decision to use state-of-the-art technology, the need for a static test program for the motor is reduced essentially to confirming, on the large-scale design, characteristics which have already been proven on a smaller scale, i.e., demonstrating that extrapolation of the scaling law extends to and includes the new, larger size.

Again, solid-propellant rocket experience should be helpful in that it has revealed the desirability of initiating flight tests of the vehicle system at the earliest possible

---

[1] Additional material in support of this study is contained in Technical Memorandum No. 33-52, Addendum A, Jet Propulsion Laboratory, Pasadena, Calif.

date. In solid-rocket propulsion, static and flight tests with "battleship" hardware tend to be program diversions of very limited value. Static tests on stages of clustered motors are unnecessary. (The high-speed clustered stages used in the *Explorer* and *Juno* Programs were developed without ground testing of clustered motors. The validity of this procedure was demonstrated by the successful flight program.)

The large size of the *Nova*-class vehicle allows for abnormally large weights and volumes for guidance, control, and auxiliary subsystems. This fact should remove one of the serious constraints imposed on current guidance and auxiliary systems and hence will allow greater freedom in the choices of proven elements, in the application of proven techniques, and in the judicious use of redundancy. The over-all vehicle system reliability should be significantly improved by capitalizing on these advantages.

Because of the above decisions and system characteristics, a program approach that is fundamentally different from that of past launching vehicle systems is advocated. The program philosophy would resemble that for bridge building more than for aircraft or missile construction. In the latter, standard approach for missile construction, testing of components and assemblies occurs after each phase in the development and before successive phases are begun. Components are tested, then combined as subassemblies for test; the subassemblies are then combined as the first stage for flight test; then the first and second stages are assembled for flight test, etc. In the new approach the vehicle is designed conservatively, analyzed using known principles, then assembled, like a bridge, for immediate use. Testing is performed primarily to confirm what is known. An important point to remember when applying this philosophy is that weight, *per se*, is not a technical obstacle. It should be considered limiting only if it grossly affects costs or technical feasibility. The engineering design philosophy recommended is one which trades size and weight for time and money.

It is important that individuals and/or organizations assigned to carry out portions of a major program such as discussed in this study participate in its early formulative stages. This approach not only stimulates their interest but provides an excellent mechanism for incorporating their thoughts and experience into the development of requirements to which they will later be committed. This philosophy is an important element in achieving early mission success.

It is assumed for the purpose of this study that the leading mission characteristics will compete in the following order:

1. Mission success (schedules and reliability).
2. Cost.
3. Growth potential.

It must be pointed out that the study has been concerned primarily with a vehicle capable of injecting 130,000 lb to escape velocity. This injection capacity was adopted arbitrarily as being representative of the current *Apollo* spacecraft studies and is here used to establish the launching vehicle scale.

The vehicle discussed is conceptual in nature and is not intended to represent a final design; rather it indicates a feasible system. Indeed, it should be stressed that further comprehensive study (as indicated in Section I-D) would be necessary if consideration were given to implementing a solid-propellant *Nova* program.

The *Apollo* spacecraft was examined briefly but only to obtain some indication of the vehicle spacecraft interface problems and for assurance that some characteristic of a solid-propellant vehicle would not prevent satisfactory operation of the spacecraft.

2. Summary

This study shows that an all-solid-propellant *Nova* injection vehicle system is technically feasible. The vehicle studied consists of a four-stage solid-propellant rocket having a gross weight in the 25,000,000-lb class. The first three steps will inject the fourth stage into a parking orbit from which the fourth step injects the spacecraft into a transfer orbit to the Moon.

From a technical standpoint, it is believed that the vehicle injection system can be made available for a manned lunar landing and return five years after the date of go-ahead. Total costs for a flight program of 20 vehicles are estimated at about $2.6 billion and include vehicle and spacecraft development and production costs, all special production facilities such as the propellant plant, launch facilities and GSE, and launch operations. The costs of astronaut training and the flight test program for spacecraft development prior to the *Nova* phase were omitted.

At this time there do not appear to be any major technical problem areas; however, early emphasis should be given to thrust vector control and to meeting guidance and control as well as other subsystem reliability re-

quirements. Combustion instability is not expected; it is believed that even if it is encountered it would not become a serious problem.

As a result of these studies the confidence of the study group in the philosophy and program approach advocated above has been reinforced. It is concluded that this approach has merits at least equal to those of any other launch vehicle system and full consideration must be given the solid-propellant *Nova* approach before final selection is made of the system or systems to be developed for putting a man on the Moon.

B. Mission Approach

The single most important question that must be answered before deciding on an over-all design philosophy relates to the acceptable level of risk associated with the mission. Many decisions of far-reaching consequence cannot be intelligently made until the level of risk is established. Some of these decisions relate to:

1. The level of reliability that must be designed into the system.

2. The amount and kind of abort capability that must be built into the system.

3. The amount of shielding that is required.

The problem of determining the actual level of system reliability is very difficult—or even impractical—to establish quantitatively. If reliance were to be placed on a straightforward flight test program to establish a demonstrated reliability record, very large numbers of test flights would be required. As an example, a series of ten successful operations with no failures implies, by elementary statistical theory, a 50% confidence level that the failure rate is less than 5% or a 90% confidence level that the failure rate is less than 25%. It thus does not appear likely that any program of the type under consideration will be based on requiring flight demonstration of a high level of reliability with a high confidence level. Instead, a program philosophy such as that used in Project Mercury, with reliance placed on more subjective judgments, is to be expected. In this circumstance, judgment must be based primarily on a knowledge of the soundness of the fundamental design and on the quality of the workmanship. A conservative design philosophy, as used herein, implies that there is a high expectation of an early achievement of an acceptable level of reliability.

C. System Description

The injection vehicle system and its industrial support complex, as examined in this study, include the vehicle, its means of production, the associated transportation complex, and the facilities needed to assemble, check, and launch the vehicle (see Fig. 1). The spacecraft is considered only as it affects the injection vehicle system. These aspects of the system are briefly described in the following sections.

1. Injection Vehicle

a. Description and operation. The injection vehicle, which consists of four steps of clustered solid-propellant motors, is shown in Fig. 2. (Conceptual designs of a liquid- and a solid-propellant *Nova* are included for comparison purposes.) The motors in a step are joined by intrastage structure; successive steps are joined by interstage structure which contains provision for positive separation. Each step has its own thrust vector control system. The fourth step carries a 130,000-lb spacecraft, the abort rocket system, the guidance, control, and telemetry systems for the injection vehicle, and a vernier propulsion system.

A typical sequence of operations for injecting a payload into a lunar trajectory would be:

1. Stage-one ignition.
2. Step-one burnout, separation, and shroud ejection.
3. Stage-two ignition.
4. Step-two burnout and separation.
5. Stage-three ignition.
6. Step-three burnout and separation.
7. Vernier velocity correction into parking orbit.
8. Coast.
9. Stage-four ignition.
10. Step-four burnout and payload separation.
11. Vernier velocity correction into lunar trajectory.

Since vernier velocity corrections are used, it is not necessary to terminate the thrust of the large solid-propellant motors. The verniers required are small rockets containing about 5,000-15,000 lb of either liquid or solid propellant. Their thrust termination is within the state-of-the-art.

The desire for flexibility in the injection vehicle with respect to requirements originating with other missions might dictate the use of a storable, restartable, liquid-propellant fourth step. Detailed consideration of this possibility is beyond the scope of this particular study.
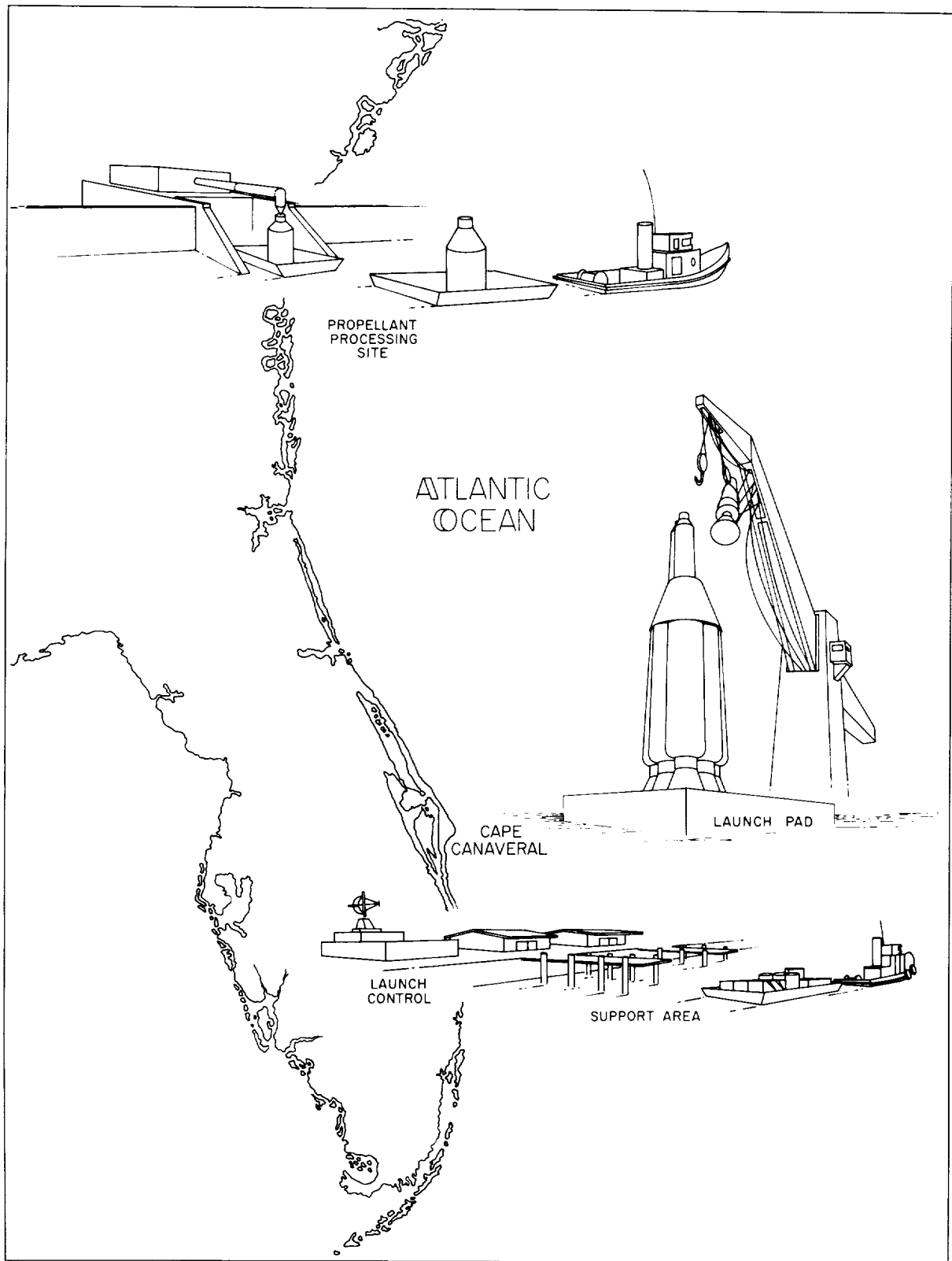
PROPELLANT
PROCESSING
SITE

ATLANTIC
OCEAN

CAPE
CANAVERAL

LAUNCH PAD

LAUNCH
CONTROL

SUPPORT AREA

Fig. 1. Solid *Nova* system
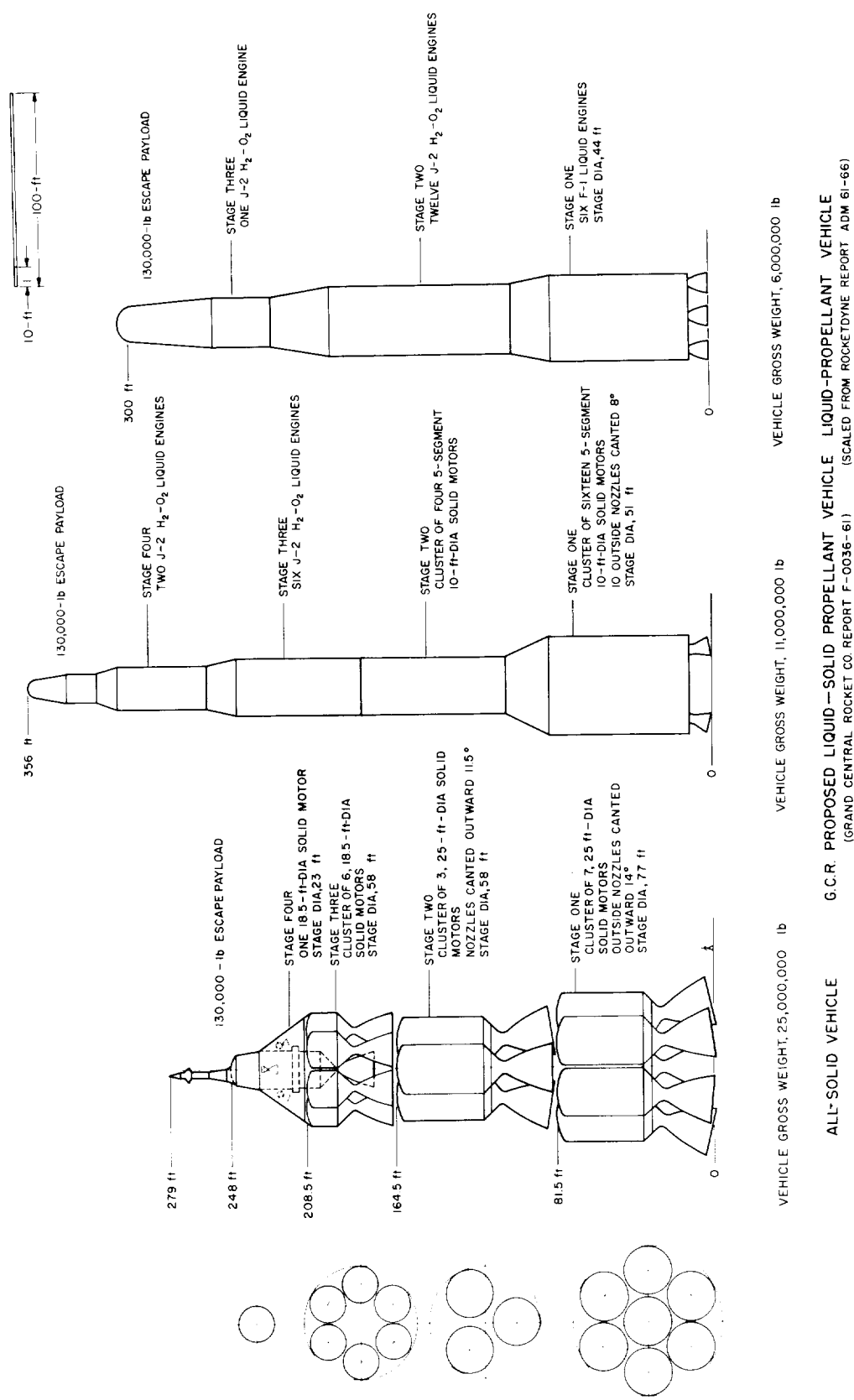
Fig. 2. Conceptual Nova designs

The injection vehicle sized for the mission considered here has a gross weight at takeoff in the 25,000,000-lb class. The diameter of the first step is 77 ft, and the height of the injection vehicle to the separation plane between the fourth step and the payload is 220 ft.

b. Performance. Performance parameters are presented in Table 1. Three-dimensional point-mass trajectories were computed assuming eastward launch from AMR. The first two stages were flown gravity-turn after a short vertical ascent. The third stage was flown at a constant inertial attitude into a circular parking orbit at 100 nautical miles. It should be noted that the maximum acceleration, occurring near the end of third-stage burning, is 5.3 g, an acceleration tolerable by man. The mass will be distributed between the third and fourth stages such that the velocity at the end of third-stage burning is slightly short of achieving circular velocity. Part of the propellant weight assigned to the fourth stage is used as a vernier control to make up this difference.

The sizing was accomplished by assuming values for the specific impulse and for the step propellant mass fraction (i.e., propellant to gross step mass). The primary considerations used in the sizing and trajectory design were performance capability, airloads, achievement of a parking orbit at the end of third-stage burning, and meeting manned acceleration requirements.

c. Propulsion. The motors designed for this study represent a typical design concept to demonstrate the feasibility of making very large units. Detailed characteristics are shown below. Motor A is used for the first and second stages, and motor B is used for the third and fourth stages.

	Motor A	Motor B
Average vacuum thrust, lb	6,400,000	740,000
Propellant weight, lb	1,900,000	350,000
Liner weight, lb	15,000	7,000
Diameter, ft	25	18
Over-all length/diameter	3.26:1	2.33:1
Grain perforation	star	star
Volumetric loading, %	82	88
Burning time, sec	85	138
Nominal chamber pressure, psia	800	350
Burning rate, in./sec	0.64	0.46

A specific impulse of 245 lb-sec/lb at 1000 psi and sea level optimum expansion was assumed. The performance parameters assumed here are all within the present state-of-the-art. The reproducibility of performance should exceed that of present, relatively small motors because continuous mixing techniques are contemplated, and large amounts of propellant are being cast.

It is believed unlikely that combustion instability will be encountered; if it does occur, modern techniques should preclude any serious delay in schedule. In recent years, powdered aluminum has been found to be an excellent suppressant for combustion instability in existing solid-propellant boosters which use ammonium perchlorate composite propellants. As aluminum quantities are increased up to 15–17%, its performance as well as its effectiveness as a suppressant increases. None of the relatively large motors that utilize these high aluminum composite propellants (*Minuteman, Polaris,* and *Pershing*) have shown any sign of combustion instability; the propellants under consideration here contain these high aluminum concentrations.

Table 1. Vehicle performance parameters

Parameter	Stage			
	1	2	3	4
Average thrust, lb	44.6 x 10⁶ (vacuum)	19.1 x 10⁶	4.46 x 10⁶	0.74 x 10⁶
	36.7 x 10⁶ (sea level)	—	—	—
Specific impulse, sec	281 (vacuum)	281	294	294
	231 (sea level)	—	—	—
Step propellant fraction	0.87	0.87	0.91	0.91
Number of motors	7 type A	3 type A	6 type B	1 type B
Total burning time, sec	85.3	85.3	138.3	138.3
Initial thrust-to-weight ratio, g	1.6	2.1	1.8	1.6
Maximum thrust-to-weight ratio, g	3.8	5.0	5.3	4.0
Velocity (ideal), fps	7040	8550	12890	10780
Velocity (burnout), fps	3800	12,800	25,460	36,140

Unitized motors were used in this study in order to investigate the ground facilities required to support this type of design. It is not necessarily recommended that they be chosen over segmented motors. However, since new propellant processing facilities will be constructed for this vehicle, they can be designed to accommodate either approach. The final decision between unitized or segmented motors should result from a study of the effects of the choice on the flight vehicle. Experience has shown that it would be undesirable to compromise the flight vehicle because of ground support equipment requirements unless a question of feasibility is involved.

Propellant will be processed in a new continuous-mix plant at a site strategically chosen for the raw material supply, its proximity to the launch site, and practicability of shipping finished rocket motors. Propellant facilities similar to those under consideration are already in production and have demonstrated the quality of product and high production rates required for the program. Aerojet-General Corp., for example, recently cast a 100-in.-diameter charge, weighing about 100,000 lb, at the indicated rate, then cured and fired it successfully. It is of interest to note that the static test record, based on high-frequency-response instrumentation, gave no indication of combustion instability.

d. Thrust vector control. A thrust vector control system is needed in each stage to compensate for the effects of center-of-gravity displacement, thrust misalignment, and unequal thrust (particularly at ignition and burnout). It must also counteract aerodynamic forces during first-stage burning. Canting of the rocket motor nozzles so that the thrust vector is directed near the burnout center of gravity of the stage helps to reduce some of these disturbances but cannot be used when the angle of cant is large. Thrust vector control systems that could be used include jet vanes, secondary injection, auxiliary rocket motors, and jet tabs. Each has distinct advantages and disadvantages, and a choice can result only from a detailed system study considering guidance, structures, and spacecraft. A jet vane system offers a feasible solution to this problem. However, a gas pressurized secondary injection system appears to be inherently more reliable and was chosen for more detailed study in order to provide a basis for weight and cost estimates.

e. Structures. The largest structural weight item in the vehicle is the rocket motor case. Fortunately, considerable experience in the design of cylindrical pressure vessels is available, and the large size considered here should introduce no problems which differ basically from those already encountered elsewhere. Consistent with the philosophy already presented, a heat-treatable martensitic steel with a yield strength of 165,000 psi was chosen in this study. Toughness and ductility should be high at this strength level. However, this conclusion is tentative until more information is available for the ¾-in.-thick material considered for the type A motor case.

The interstage structure, as presently conceived, is either a space frame or a set of three braced columns. Loads would be transmitted to the motor cases as concentrated loads acting on truss pads attached to the motor domes or as concentrated line shears. This technique was used on the *Sergeant* motor case and is extensively used in large water tanks and pressure vessels in the power generating and chemical industries.

Two types of rocket nozzles were considered: (1) a graphite-steel, heat-sink type, and (2) ablating plastic nozzles. The use of ablating nozzles appears very attractive for this application because the linear ablation rate will be the same or slightly less than that of smaller engines, and, therefore, the percentage change in throat area will be acceptably small. Either type appears feasible; scaling laws predict less severe conditions than for existing nozzles despite the relatively long burning time, provided that weights are scaled with impulse.

f. Structural dynamics. Major structural dynamics effects such as over-all dynamic loads and dynamic stability were examined qualitatively to ascertain whether extrapolation in size or weight would adversely affect the feasibility of the solid *Nova*. By using aeroelastic model theory, and by assuming that dynamic magnification factors associated with transit through discrete gusts are independent of size, it can be shown that a large vehicle should encounter less severe loading in relation to its strength than a small vehicle which is dynamically similar.

Dynamic instability of the type characterized by adverse coupling between the autopilot and the elastic airframe can become a serious problem if a conventional flight-control sensor installation is employed. However, "transducer arrays"—e.g., a number of attitude gyros discretely positioned over the length of the vehicle with outputs electrically summed—can be employed to suppress the coupling of the autopilot with body bending modes. Thus, low bending mode frequencies, *per se*, need not lead to dynamic stability problems.

The solid-propellant vehicle system carrying liquid payload rockets or a liquid secondary injection system poses relatively trivial liquid sloshing problems because of the low percentage of liquid mass.

The solid *Nova* development philosophy advanced herein places a major reliance upon the employment of scale models. In the structural dynamics area, it is considered that effective support can be given to the design effort and to the subsequent evaluation of the finalized design by recourse to model tests. The theory of aeroelastic model design is well developed, as are techniques for building such models. In the subject application, freedom from major liquid sloshing problems permits practical attainment of dynamic similitude in model design and test. Construction of, for example, a tenth-scale dynamic model for modal vibration surveys would permit simulation of local structural details such as bolted joints and use of dummy propellant having the proper density and viscoelastic properties. Smaller-scale aeroelastic models for wind tunnel test may be compared, through modal vibration tests, with the one-tenth-scale "reference" model.

g. Aerodynamics. The need to aerodynamically shroud the vehicle has been examined from the aspects of heating, drag, and unsteady flow effects.

Maximum laminar and turbulent heating rates were examined for the velocity-altitude information obtained from a powered flight computer trajectory. A conservative analysis indicates that heating will be no problem on exposed structural members or motor cases.

An estimate of the aerodynamic drag for a body of this type is not readily calculated. The examination of some experimental data and calculations based on two simple drag models indicates that the peak drag-to-thrust ratio is approximately 0.15, an acceptable value.

Unsteady flow effects between motor cases may result in high local vibration loads. Local fairing should alleviate this condition. In none of the cases studied could a positive requirement for shrouding be determined. Consequently, only a shroud from the payload to the top of the fourth stage has been indicated. The weight of this shroud was charged to the first stage, since it would be discarded at the end of first-stage burning.

The maximum dynamic pressure expected is approximately 1400 psf, and at first-stage separation the dynamic pressure is approximately 40 psf. These pressures are acceptable for the vehicle under consideration. Trajectory shaping can be used to reduce the maximum pressure to a value less than 1000 psf, if desirable.

h. Assembly and alignment. With proper attention paid to details, assembly and alignment should provide no difficulty. Provision will have to be made for a temporary framework to support the motors of a stage during construction until the stage is structurally tied together. Erection loads on the individual motor cases will have to be considered in their design. Vehicle loads caused by wind and wave action during storm conditions while on the launching pad are expected to be small for the blunt, dense, solid-propellant vehicle, and temporary guys or bracing are adequate protection.

Techniques are available to provide center-of-gravity control without measuring absolute weight. If further study indicates that accurate absolute weight measurement is required, an increase in the existing capability for accurately calibrating load cells is required. Load cells of the necessary size are available.

i. Guidance requirements. The guidance of the vehicle has not been examined in detail, but it is felt that no unusual problems will be present. The general philosophy of this program can be applied to the guidance area, and adequate space with a controlled environment and ample weight for the required equipment have been provided. The weight should allow for underrating components and providing redundancy wherever needed.

Since it is considered that midcourse correction capacity will be required in the spacecraft, the precision and performance required of the injection vehicle are not extreme. Indeed, guidance capability equivalent to that required for military weapons is adequate.

It should be noted that the general concept of launch, injection, midcourse, and terminal guidance of the vehicle as well as its spacecraft, controlled in part from the Earth,[2] is considered to be appropriate for this mission. Participation in the control by men on board should be limited to emergency measures only.

j. Design conclusions. Weight estimates for all of the steps in the injection vehicle have been based on the technical studies described above. As a result of this study it is concluded that a four-stage solid-propellant injection vehicle in the 25,000,000-lb class is feasible and is capable of performing the desired mission.

2. Development Plan

Consistent with the philosophy advocated in this study, the following development plan is proposed. Carefully planned, limited-purpose, small-scale tests will be used as a design tool to illuminate problem areas and to provide design tools or measures of reliability and add a

---

[2]Midcourse guidance is preferably although not necessarily controlled in part from the Earth.

measure of confidence and refined technical information to the development program.

Small-scale testing will satisfy most, if not all, of the requirements for design information within the first two years of the program. In fact, certain tests should be initiated along with design study in specific problem areas which can be defined early in the program. The small-scale test program will include:

1. Motor cases tested under pressure, concentrated loads and combined loads to provide design information and to confirm design techniques.

2. Prototype scale vehicles tested statically and dynamically to provide information on interaction effects, dynamic behavior and ultimate strength.

3. Wind tunnel models to provide rigid body and aeroelastic aerodynamic information.

4. Motors static fired to provide information on the charge design, nozzle, case lining and insulation, and thrust vector control.

5. Ignition tests, performed on a motor with a small web and the full-scale internal propellant geometry to provide design information.

6. Thrust vector control system tests to provide information on interaction effects and design information.

7. Miscellaneous tests on other structure, separation devices, and ancillary equipment.

The full-scale test program is relatively small and consists of:

1. Motor cases tested under pressure, concentrated loads, and combined loads.

2. Type A and B motors static-fired with active thrust vector control.

3. Miscellaneous subsystem elements such as the separation joint and some of the elements of the interstage structure.

It is important to note that the program approach and philosophy obviate the need for much of the conventional development and test program including all full-scale cluster static firings, full-scale structural dynamic testing, and boiler plate or partial vehicle flights normally associated with a vehicle program. These deletions result in a large saving in over-all program costs and development time.

3. Producibility

The producibility of solid-propellant engine processing facilities and raw materials, engine hardware fabrication including facilities and materials, and interstage and intrastage structure has been considered. It is assumed that rigid quality control would occur throughout all stages of manufacture and assembly of the vehicle.

Most of the manufacturing problems are associated with the large motor cases. Figure 3 shows some of the possible methods of manufacture. Material supply is assured, since the program under study would require less than 1% of the nation's current production of low alloy steel. However, new fabrication facilities will be required. It is recommended that they be located adjacent to navigable water because of the size of the manufactured items.

About one million square feet of space is required. A shear spinning machine and a gantry furnace with associated utilities are the only major additional items required. The rest of the metal hardware needed, although large, should provide no greater difficulty in terms of facilities or techniques than will the cases.

4. Facilities and GSE

Because of the size and nature of the program, some specialized facilities and operations are needed. These are examined briefly in the following material.

a. Propellant processing facility. Because of the quantity of propellant needed and the size of the loaded motors, water transport at the propellant processing facility is required.

The site should (1) be convenient to Cape Canaveral (the assumed launch site) by barge transport, preferably through an inland waterway to avoid long exposure to the open sea, and (2) provide in-plant barge transport during processing.

There are many islands and coastal areas from Texas to South Carolina that could meet the above requirements. A typical site, Skidaway Island, in Georgia (Fig. 4), has been chosen only to demonstrate the feasibility of such an approach. It is assumed that the island is undeveloped and that all waterways used during processing will be dredged completely. A description of the facilities is given in **Table 2.**

The propellant materials considered are typical components of propellants now used in large motor programs. New production capability is required for all of the ammonium perchlorate used in this program (8,000,000 lb per month). Power requirements for this production

BARREL SECTIONS   HEADS

ALT I	ALT IA	ALT 2	ALT 2	ALT I
INGOT 14-16 tons	2 PLATES 5 ft × 40 ft × 2½ in.	2 PLATES 10 ft × 40 ft × 0.75 in.	FORM PIE SEGMENTS FROM STOCK OF APPROPRIATE THICKNESS	SHEAR SPIN ONE PIECE HEAD FROM FLAT DISC

ALT I (Barrel): INGOT 14-16 tons → PIERCE → RING ROLL TO 24 ft DIA. × 5 ft LENGTH × 2½ in. THICK → AIR ANNEAL → SCALP → SHEAR SPIN TO 24 ft × 10 ft × 0.75 in → TRIM

ALT IA (Barrel): 2 PLATES 5 ft × 40 ft × 2½ in. → ROLL FORM OR FORGE BEND → WELD ⟶ (to AIR ANNEAL)

ALT 2 (Barrel): 2 PLATES 10 ft × 40 ft × 0.75 in. → TRIM → ROLL FORM INTO SEMICIRCLES → MACHINE WELD GROOVES → ASSEMBLE FOR WELDING → WELD 2 SEAMS → TRIM

ALT 2 (Heads): FORM PIE SEGMENTS FROM STOCK OF APPROPRIATE THICKNESS → MACHINE WELD GROOVES → ASSEMBLE → WELD → TRIM

ALT I (Heads): SHEAR SPIN ONE PIECE HEAD FROM FLAT DISC → TRIM

ATMOSPHERE HEAT TREAT AUSTENITIZE, QUENCH, DRAW

MACHINE WELD GROOVES FOR GIRTH WELDS → ASSEMBLE IN WELD TOOLING → WELD → STRESS RELIEVE BY LOCAL HEATING → APPLY REINFORCING BANDS IF NECESSARY
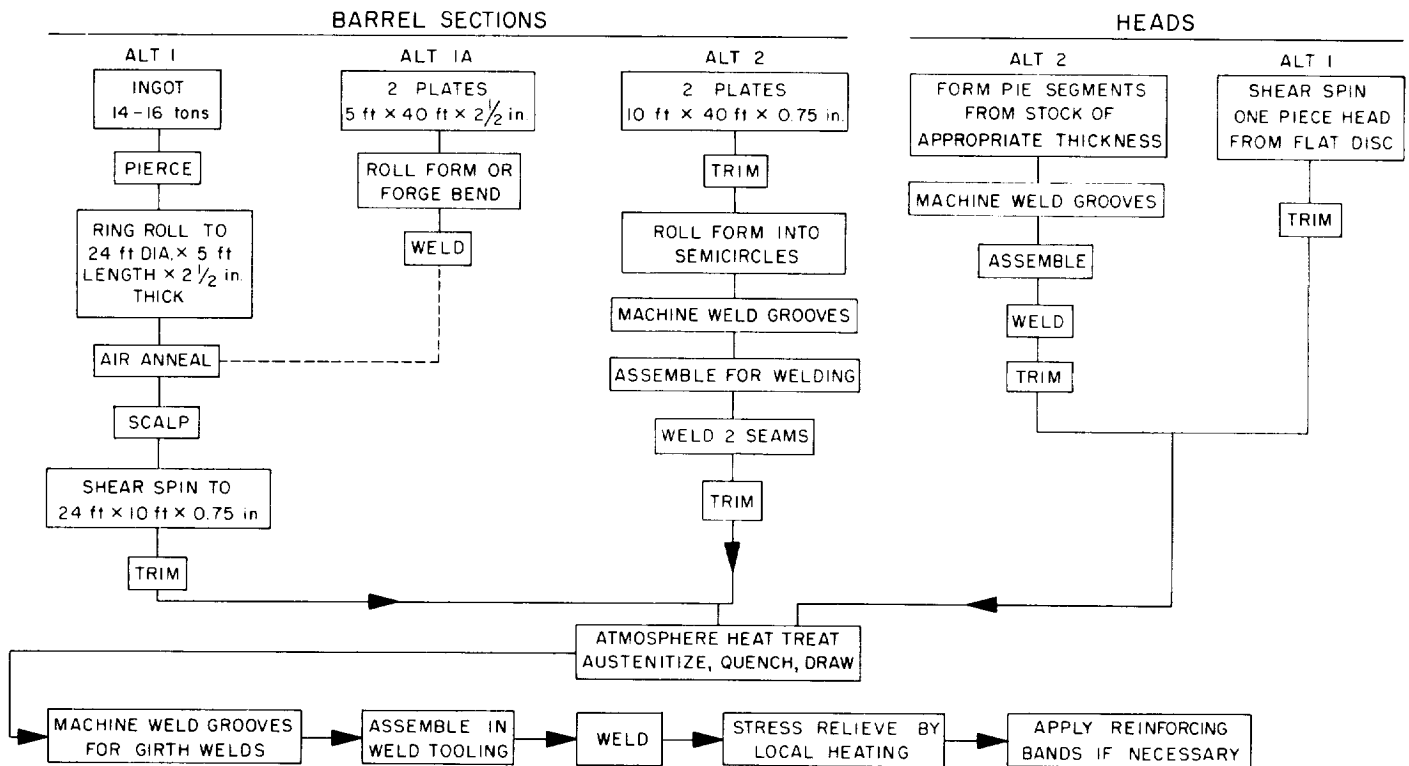
Fig. 3. Possible manufacturing methods

are not excessive. The other materials required are readily available or could be made available on relatively short notice.

Propellants of the type under consideration, at the operating temperatures to be used, have never been known to detonate. Nevertheless, all facilities have been sized and sited on the basis of class 9 or 10 propellant because no experience at this size is available.

b. Launch site operations. The launch site, ground support equipment, and assembly and transportation techniques are governed by the following criteria: (1) the complex must be in operation within 2.5 years of the commencement of the program if it is to be used for motor static test firings; (2) it must be an economical and practical system for accomplishing this task; and (3) the possibility of loss, because of a launch failure, of costly and long-lead-time ground support equipment must be minimized.

The launch site is assumed to be located near existing range facilities and sources of manpower. The use of Cape Canaveral with its complete range system and support services as well as its years of extensive use is assumed here to be the chosen site. It is evident that the solid-propellant *Nova,* because of the acoustic and explosive safety distances involved, cannot be launched directly from the Cape. The choice of an offshore launching pad is indicated when the additional launch complex requirements are considered.

In determining support systems for the assembly and launching of a vehicle of this size, it is useful to observe the experience which exists in other fields of endeavor. Normal operations in the large civil engineering industry and in marine and naval architecture closely parallel the erection and handling techniques required for this vehicle. It is from this existing technology that the optimum solution should be derived.

Fixed underwater supporting structures for the depths required are encountered in bridge foundations and dam construction. Shipment of the weights required occurs daily in normal tug and barge operations. The erection and assembly of large pieces of equipment is within ship building and repair technology. Indeed, the largest man-made moving objects are ships of one form or another.

Thus, the optimum launch complex to meet the stated objectives is a fixed offshore launch pad, supported by vessels and barges and utilizing the Cape Canaveral range and support facilities.

c. Transportation and storage. Loaded solid-propellant rocket motors are stored in their respective loading
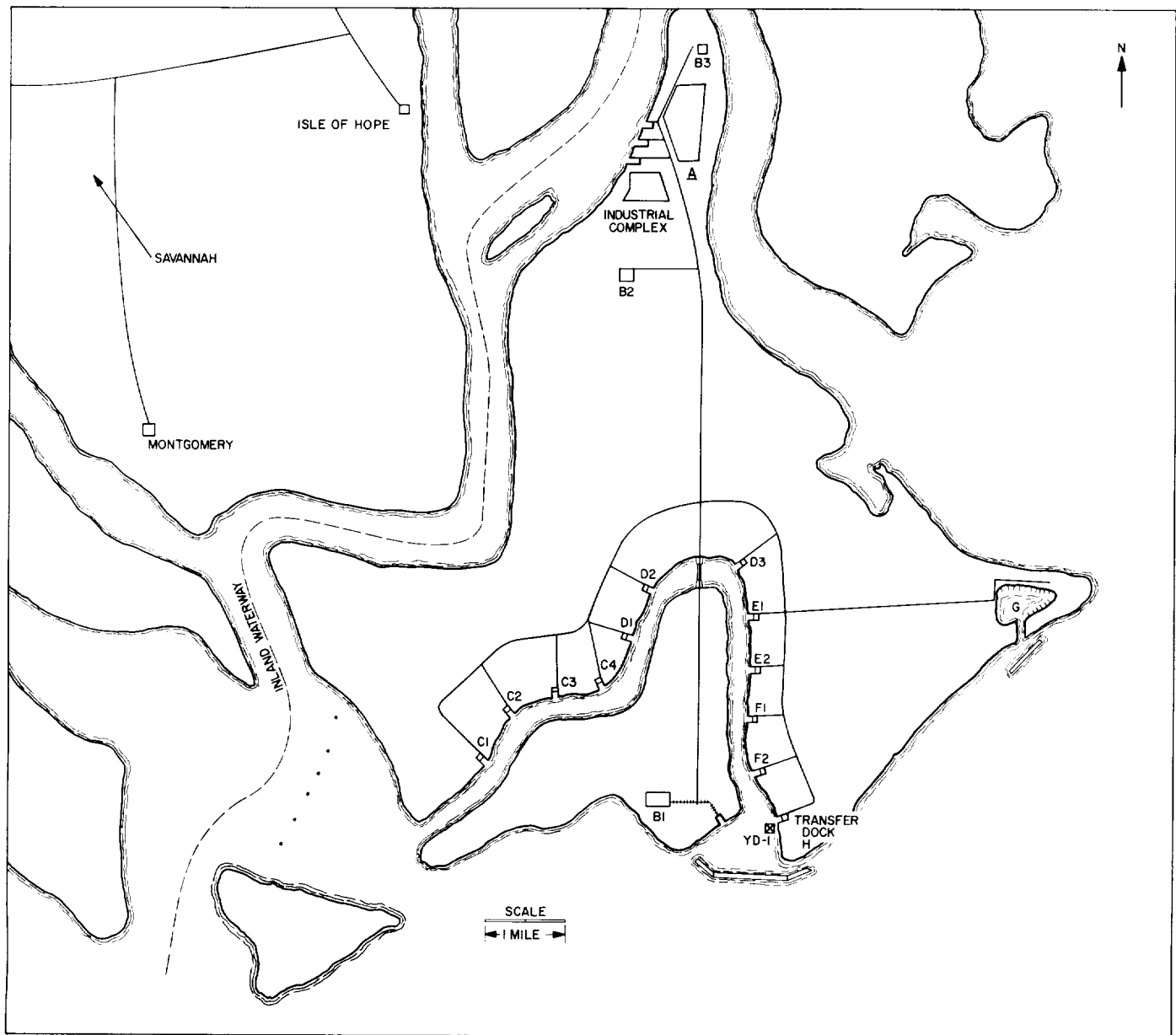
Fig. 4. Propellant processing facilities

barges at the propellant processing site. Motors are transferred from the loading barges to the transport barges by the floating crane at the processing site. They are then tugged to the launch site at a rate determined by the launching schedule.

Guidance, telemetry, and associated equipment is transported to the launch support area at the Cape by conventional means. After checkout and maintenance, the equipment is barged to the launch pad for installation.

d. Site construction. Since vehicle assembly and checkout procedures require four months (Fig. 5), two launch

pads are required to allow launchings on two-month centers. These pads (Fig. 6) would be placed approximately 6 to 12 miles off the coast of Cape Canaveral with a similar distance separating them for acoustic and quantity-distance safety requirements. The launch pad would then be in 60 to 100 ft of water. This depth is typical of that found in bridge foundations, and this construction is the type desired. For a solid-propellant vehicle, the dimensions of the pad need only be large enough to provide structural support for the vehicle. The large weight of the vehicle as erected provides considerable stability against overturning caused by wind and

Table 2. Physical descripiton of facilities

Designation	Number of Units	Components of Each Unit
Facility A, case processing	1	Standard industrial buildings including mixers for preparing liners and insulation
		Equipment for weighing, cleaning, lining, and insulating the chamber
		Three receiving docks
Facility B1, storage of Class 2 materials	1	Storage buildings with revetments, drying and grinding units for ammonium perchlorate, one dock
Facility B2, storage of Class 1 materials	1	Storage tanks and buildings
Facility B3, engineering office building and raw material quality control laboratory	1	Office building, chemical laboratories
Facility C, mixing and casting of propellant	1	Fuel premix station, storage tanks
	4	Two 1.5×10^6 lb/month mixing plants, similar to the plant now in operation at Aerojet-General Corp; propellant is pumped over a boom to the motor
		One casting dock with corrugated rain shed
Facility D, curing	3	One curing dock with rain shed, power supply for heating mantles
Facility E, final motor processing	2	One assembly dock with rain shed
		Tooling for loosening and removing the mandrel, trimming the propellant, and mounting the nozzle
Facility F, inspection	2	One dock with more elaborate overstructure for inspection equipment
		Inspection units
Facility G, storage	1	A dredged lagoon with sufficient weather-protected docks for storage of motors for 2 complete vehicles
Facility H		Two transfer docks, floating crane

storm conditions. Hurricane protection is limited at most to temporary guying and bracing. All auxiliary operations emanate from the crane or support vessels. A hold-down structure is neither desirable nor practical for use during the launching of a solid-propellant vehicle.

A breakwater of one mile in over-all length is required to shelter each pad area sufficiently to allow shipborne operations in all but gale conditions. This breakwater is of rock construction and 10 ft above high tide.

General support, electronic checkout, engineering personnel, and auxiliary equipment receiving and storage buildings are located on or near the Cape. Several docks and a crane (YD-4) are required to transfer this equipment to barges for transport to the launch pads.

The distance off-shore between the pad and the Cape has been specified as that allowing for inhabited areas, according to the mass of propellant involved. The Launch Control Center is, therefore, not a blockhouse in the normal sense, but is structurally an ordinary building, located on the Cape in the general support area. This Center contains the launch control instrumentation and equipment and is connected to the pads by underwater cable for phone and electrical connections. Most of the prelaunch instrumentation and monitoring measurements are made, however, by direct radio link between the vehicle and the Launch Control Center.

An umbilical mast provides electrical connections to the spacecraft up until launch, as well as emergency de-arming or astronaut exit ladders. This mast pivots at its base and drops to the water at launch.

e. Vehicle assembly equipment. The primary assembly problem is the erection and handling of the first- and second-stage motors. A crane of 1,000-ton capacity and 200-ft hook height is required, with a secondary hook of 200 tons and 300 ft for the upper stages and payload.
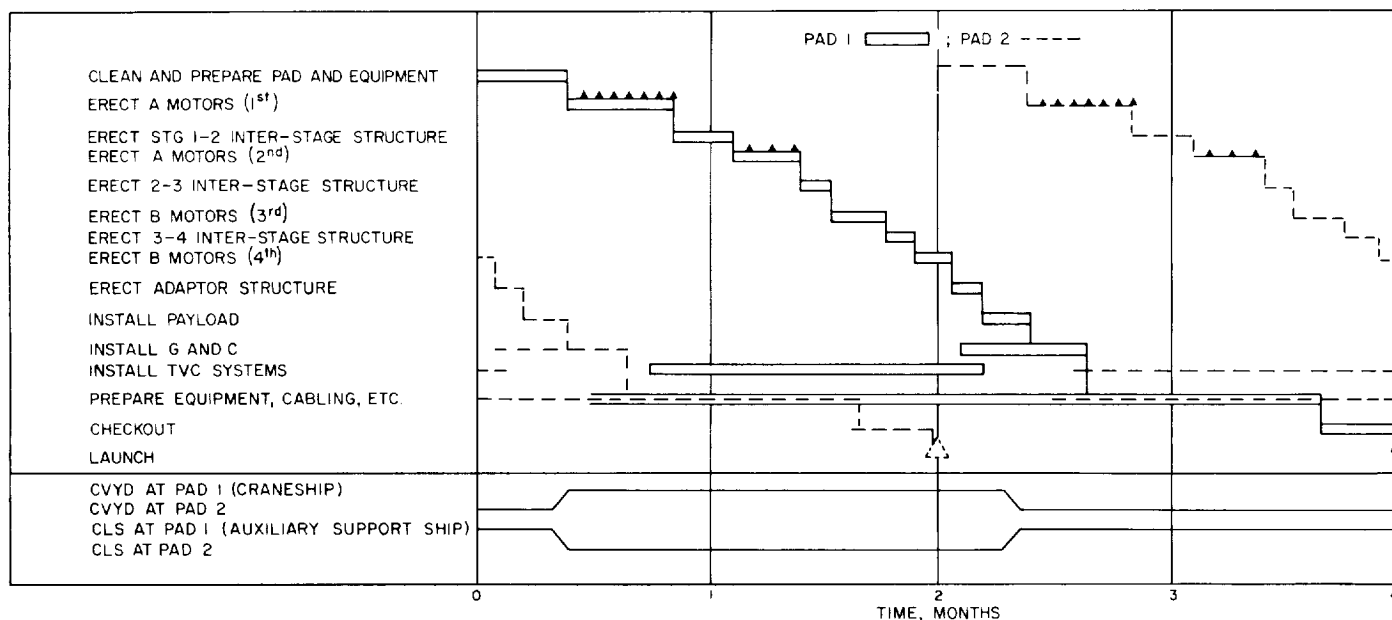
Fig. 5. Launch operations schedule

The construction and operation of this crane and its support structure are considerably simplified when based on water-borne operations. Currently, the largest movable crane in the United States is the Navy YD-171, mounted on a self-propelled floating barge. This is one of four constructed in 1941 and has a 450-ton capacity and 160-ft hook height. Several fixed cranes of this capacity, but with lower hooks, also exist.

Construction of the crane required is considered quite feasible, and two options for its flotation are available.

A scaled-up version of the flat-bottomed barge and crane may be specially constructed for this purpose and built to contain personnel and service areas. A second method is the mounting of this crane on a demothballed World War II aircraft carrier (CVYD) of the Midway Class (**Fig. 7**). This method has several desirable secondary features. It supplies an essentially self-contained mobile field unit for personnel, power, and work area at a nominal demothballing cost. Prior to the YD-171, the largest naval crane utilized this same technique; it was constructed amidships on the Kearsarge, an obsolete pre-World War I battleship.

The use of a floating crane for the handling and careful positioning of very large loads is a well-established procedure. It provides the most economical and shortest-lead-time solution to the erection problem and allows for convenient removal from the pad area prior to launch.

Personnel service platforms around the vehicle are made in prefabricated sections and are attached directly to the vehicle structure. The loads introduced are small compared to the load-carrying ability of a solid-propellant vehicle skin. Personnel access is via an elevator tower on the craneship and gangwalks across to the vehicle. The platforms are removed prior to flight.

An auxiliary support ship (CLS) with an elevator tower for crew access is required. This ship provides checkout services and a nominal-capacity hoist for the removal of personnel scaffolding and small gear and test equipment.

f. Static testing. The full-scale static test firings of the individual full-sized motors can be conveniently accomplished at one of the launch pads. A motor, supported by suitable structure, can be mounted in an inverted position on the pad. Normal launch control instrumentation is used for this series of tests. The alternate pad is used for the first flight vehicle. Upon completion of the static test program, the external support structure is removed, and this pad is converted to a flight pad for the second flight firing.

Alternatively, a separate static test stand can be constructed and utilized for this purpose. The additional area and cost for this test stand are included in the cost analysis.

g. Field operations. A flow diagram of the field operations is shown in Fig. 6. Individual motors of types A
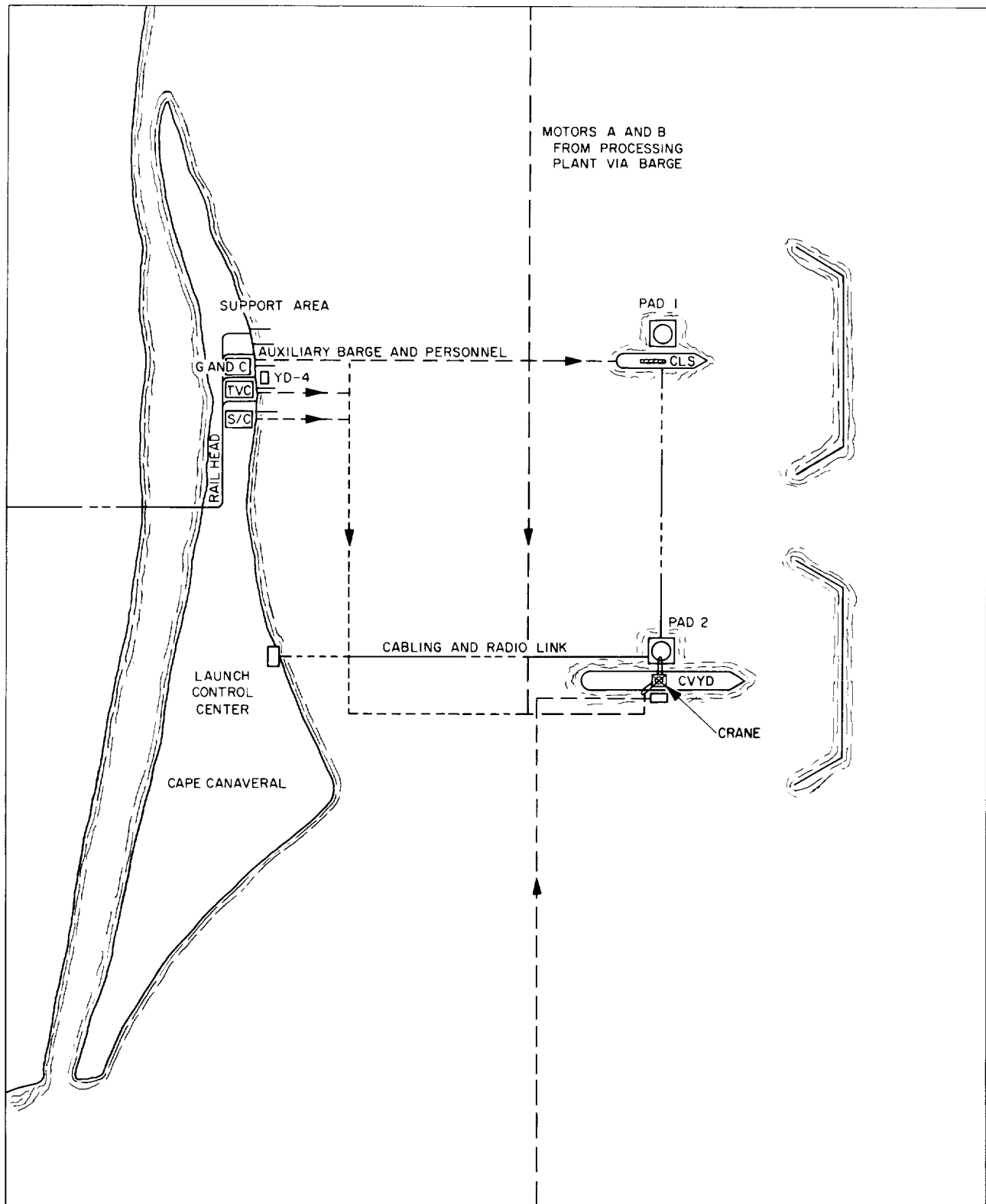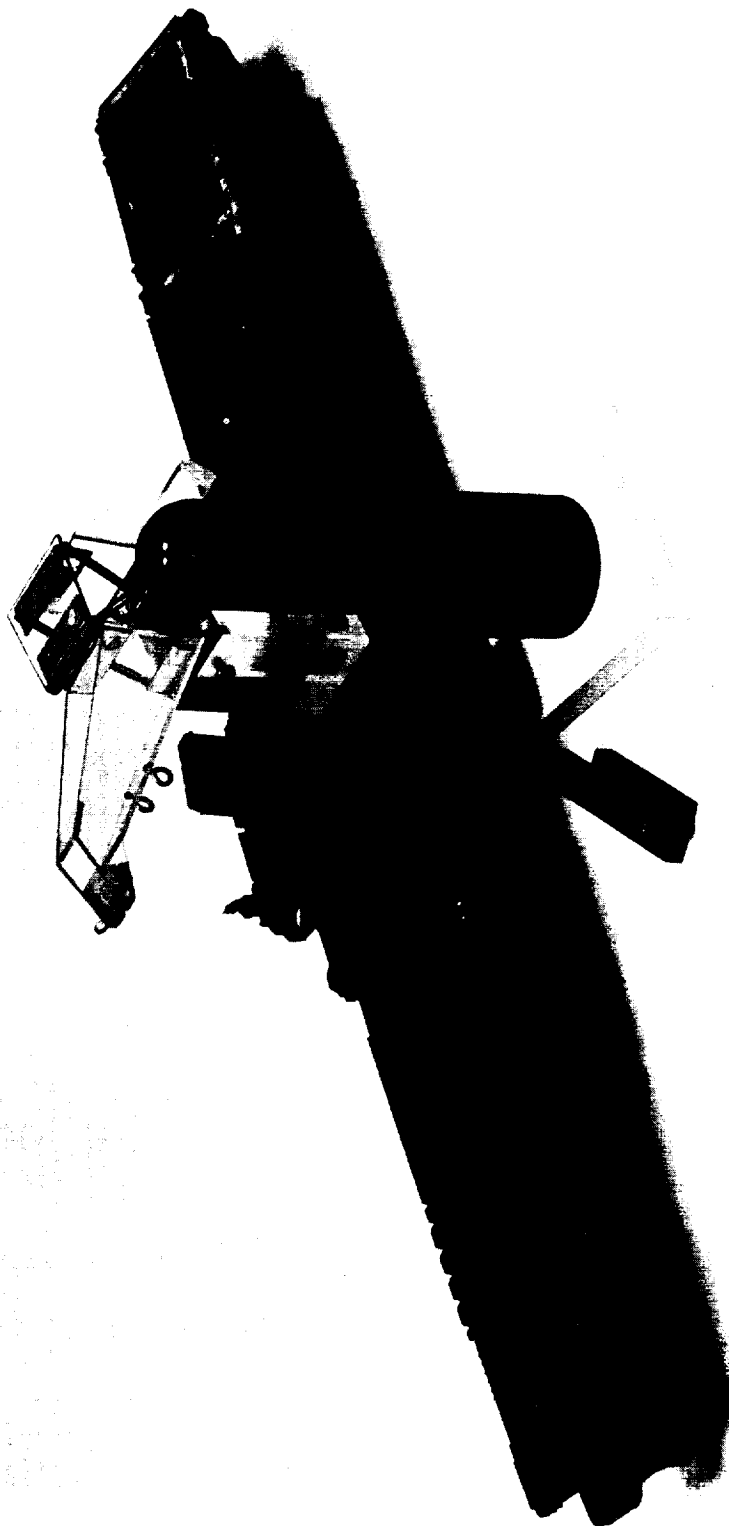
Fig. 6. Launch and support complex

Fig. 7. Pad assembly

and B arrive at the launch complex by barge from the propellant processing plant storage area. They are erected and assembled on the launch pad by the craneship (CVYD) or crane-barge. Interstage structure, in large prefabricated sections, is barged out from the Cape support area and erected. The payload and thrust vector control devices are also barged out and installed. The crane-ship is then transferred to the alternate pad and is replaced by the auxiliary support ship (CLS). During the remaining period the guidance and control, telemetry, and spacecraft equipment together with auxiliary gear is installed and the final checkout operations are accomplished prior to launch.

The firing of this vehicle from an offshore location at the Cape presents no extraordinary problems with respect to range procedure. Normal down-range tracking, range safety, and launch monitoring are identical to regular Cape launchings. Firing windows are reasonable and the actual final countdown time for the multistage solid-propellant vehicle is relatively short compared to that for existing vehicles.

5. Spacecraft Considerations

Spacecraft studies have been limited to crude feasibility determinations based on (1) 130,000-lb injected weight, (2) configuration constraints, and (3) spacecraft design problems peculiar to the employment of the solid-propellant *Nova* for a manned lunar landing and return mission.

The results of the studies can be summarized as follows: (1) there are no spacecraft design problems peculiar to the solid-propellant *Nova*; (2) the injection capabilities of the solid-propellant *Nova* appear to be adequate for a manned lunar mission; (3) there are no major spacecraft configuration constraints or limitations due to the injection vehicle.

For the purposes of this study, *Apollo* three-man mission and command modules have been arbitrarily assumed. Mission abort capabilities are assumed to be consistent with the guidelines established by the Space Task Group.

It is recommended that the spacecraft be capable of accomplishing the entire mission automatically. Men would perform monitoring functions associated with the control loop and would help implement scientific measurements and observations. Manned override control capabilities would be provided for emergencies to maximize mission reliability for the manned phases. A possible feature for a manned mission would be prior provision of an alternate return vehicle on the surface

of the Moon as a contingency for possible failures during landing. In this event, man would be equipped to transport himself over the lunar surface from one vehicle to another.

Of all the spacecraft environments associated with a solid-propellant *Nova* (vibration, linear acceleration, acoustical, etc.), the one which appeared to be most severe when compared to a liquid-propellant vehicle of the same capability is the acoustical environment. Differences in the other environments are minimal.

An analysis of the acoustical environment has been made based on extrapolations from data for smaller engines. However, the results are considered to be conservative. The calculated sound pressure levels are:

$$L_p \, (solid) = 167 \text{ db}$$
$$L_p \, (liquid) = 161 \text{ db}$$

These levels correspond to a distance of 200 ft from a solid-propellant vehicle with 40,000,000 lb of thrust or a liquid-propellant vehicle with 9,000,000 lb of thrust.

Actually, the lower exhaust velocity of a solid-propellant motor causes it to have a lower acoustic efficiency, so that the pressure level from a liquid-propellant vehicle might well be higher than that from a solid-propellant vehicle. In any case, it is important to note the high pressure level from either.

Factors such as sound absorption in the air (which increases at these high intensities because of nonlinear damping) and directivity of the sound should decrease the levels by 20 db. Reflection from the pad could be minimized by flowing water under the booster at liftoff. These factors suggest taking the pressure level as 150 db.

The ears of the astronauts are most sensitive to the acoustic field. The effectiveness of ear protectors is limited by bone conduction to about a 40-db reduction. Thus the pressure level at the ear will be reduced to 110 db, which is below the threshold of discomfort at 120 db and well below the threshold of pain at 140 db. The maximum total recommended level for speech comprehension is 110 db, so that talking with the astronauts during liftoff may be difficult, although additional attenuation by the cabin walls may make it reasonable.

It should be emphasized that the attenuation of the sound with distance is critically important.

D. Program Schedules

Figure 8 presents schedules for the over-all system including the vehicle, propellant processing, and launch

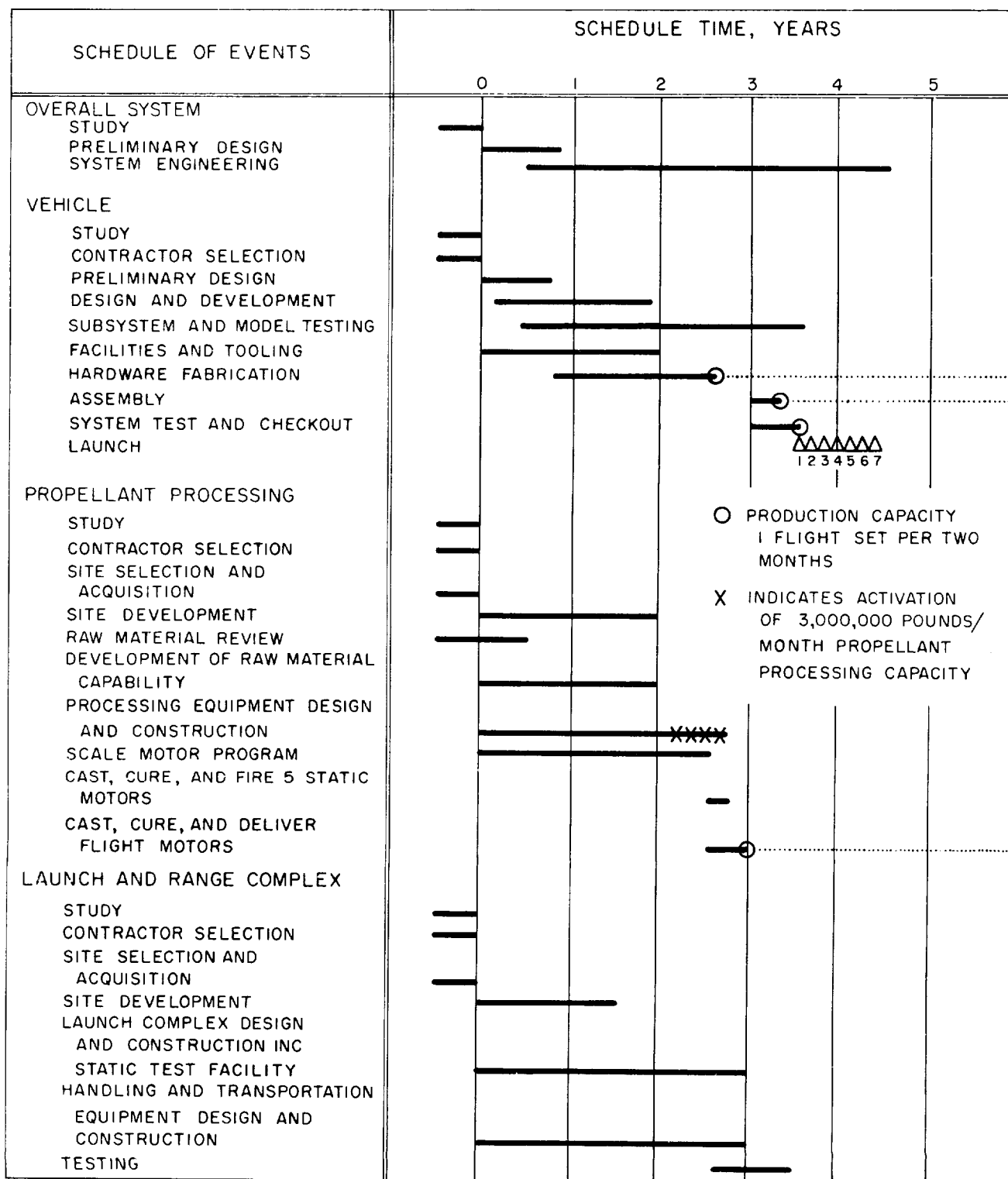| SCHEDULE OF EVENTS	SCHEDULE TIME, YEARS

Fig. 8. Program schedule

and range complex. The schedules shown are believed to be those which would be pacing items in the vehicle program. A spacecraft schedule is not shown because insufficient study was made to determine whether or not it is a pacing item.

Seven launch dates appear in the vehicle schedule. The first two are intended as propulsion rounds wherein the primary emphasis will be to evaluate the performance of the vehicles as a system. The next four are spacecraft flights. The primary objective of these four flights will be to gain knowledge and confidence in the various events which would ultimately occur during a manned lunar landing and return. It is believed that the successful accomplishment of the first six flights will result in sufficient knowledge and confidence to enable the seventh flight to carry men to the Moon and return.

There are a number of factors in a program such as is proposed which generally occur at the beginning and which are impossible to schedule at this time. As a result of this, the time 0 (zero) shown in the schedule is not a calendar date, but is a time which is dependent on completion of the following items:

1. The program shall be approved and funded to permit immediate pursuit of preliminary design with follow-on approvals and funding to occur so that schedule delays are obviated.

2. A minimum of six months of study shall have occurred prior to time 0 (zero), during which time the application of the solid propellant *Nova* to the lunar mission shall have been verified in depth and the technical requirements and preliminary design specifications generated.

3. Major contractor qualifications shall have been determined and major contractors selected. These contractors' personnel shall be available to start preliminary design.

4. Site requirements shall have been established, sites selected, and immediate availability established for launch complexes, propellant processing, loading, storage, and any other major sites required.

An important feature to be stressed is that a six-month period is devoted to study of the vehicle system in depth in order to specify the system and industrial complex requirements. During this period major and pacing contractors will be selected.

It is desired that contractors participate in the study if possible; however, it is required that key personnel from each of the major contractors participate in the nine-month preliminary design. As this work proceeds it is expected that the contractors will make commitments to carry out their portion of the program.

In addition to the schedules which have been presented, it is felt that some comments which compare inherent schedule characteristics of liquid- and solid-propulsion system development programs are warranted. It is believed that the comparisons which are made justify the belief that an inherently shorter development time is required for a solid-propellant propulsion system than for a liquid-propellant propulsion system with the same reliability.

1. A solid-propellant motor is comparatively simple. However, it has limited capability; that is, it is difficult, if not impossible, at present, to use a solid-propellant motor when there are requirements such as restart and throttling. Liquid-propellant systems are at present more complicated. However, restart and throttling are rapidly achieved. As used in the proposed system, a complicated system is not required, and the inherently simpler solid-propellant motors suffice for the job.

2. The interaction of the propellant in a solid-propellant motor with its flight environment is practically negligible. That is, there are no internal ballistics problems which can occur in flight that are not revealed by static testing. This usually results in a higher reliability with the solid-propellant vehicle at a given early date in the flight development program.

3. In a solid-propellant system, the majority of subsystems can and must be developed concurrently, and interactions between subsystems are usually minor. It is fairly typical in a liquid-propulsion system that the development of subsystems is carried out in a sequential manner, and the interactions between subsystems frequently cause multiple iterations during the development.

4. Size scaling has been repeatedly demonstrated in ratios in excess of that required for the proposed solid-propellant engine program. Size scaling is more uncertain with liquid systems.

5. Insofar as the propulsion units are concerned, there are few operations which need to be checked at the launch complex. Thus, the launch complex and the ground support equipment are inherently much simpler than are the launch complex and GSE for a liquid system.

6. In a liquid-propellant system, it is necessary to perform many operations in flight such as the metering in total quantity and proper proportions of propellants which are to be burned. In a solid-propellant motor, these operations are performed in the factory.

E. Program Costs

It is expected that in 5 years this program will allow the successful placement of a man on the Moon and return, at which time approximately $1.9 billion will have been spent.

Costs have been estimated (Table 3) based on a flight program of 20 rounds extending over a time period of 7 years. For this program the total cost is approximately $2.6 billion. Included are vehicle and spacecraft development and production costs, all special production facilities such as the propellant processing plant, launch facilities and GSE, and launch operations. The

astronaut training program is not included. Launch from an offshore pad at AMR is assumed.

1. Vehicle Costs

The major portion of the study effort was directed toward the injection vehicle. Cost studies were also aimed principally at the vehicle. Both development and production costs have been estimated.

To understand such features as development time, reliability, and cost of this boost vehicle program, it is necessary to have the underlying concept of the injection system clearly understood. This concept states that the inherently simplest and most reliable rocket motor shall be merely scaled up to provide the desired injection capability. Complication or advancements in the state-of-the-art shall not be introduced to save weight or increase performance. Application of this concept has many important side benefits. Among these benefits is a comparatively small development program and very little full-scale testing. This fact, along with the inherently

Table 3. Cost summation

	Development, $ millions	Production (based on 20 vehicles), $ millions
Vehicle		
Airframe and motor cases	87	221
Rocket motor propellant and processing	60	440
Auxiliary equipment	73	31
Guidance, communication, and power	90	66
Launch operations	—	27
Launch and support personnel	10	105
	320	890
Facilities		
Propellant processing facility	115	
Ammonium perchlorate plant	30	
Motor case and nozzle facility	115	
Launch pad and GSE	110	
Launch base	33	
Static test facility	15	
Transportation and storage	23	
	441	—
Injection system total	761	890
Spacecraft		
Command and mission module	500	140
Landing and return bus	250	70
Propellant and miscellaneous		10
	750	220
Program total — development	1511	
Program total — 20 flight program		1110
Total — development and 20 flights	2621	

simpler production characteristics of a solid rocket, results in a low-cost vehicle program.

a. Airframe and motor cases. The development program for the primary structure consists largely of design engineering of the full-scale structure and a small-scale program for structural and dynamic testing. Only motor case pressure testing and concentrated load testing will be done at full scale. Production costs were computed at $4/lb for motor cases, $10/lb for nozzles, and $5/lb for interstage and intrastage structure.

b. Rocket motor.

1. Motor development. The major elements of the rocket motor development program are a subscale development program for the two rocket motors and a full-scale program of five static firings for each motor discussed earlier under Development Plan (Section C-2). No full-scale captive firings of a cluster are planned.

2. Propellant processing. Eight continuous process lines similar to the one currently in operation at Aerojet-General Corporation are required to provide sufficient capacity for the proposed firing rate. Based on costs from the operating line and allowances for the larger scale motors, an operating cost of $1/lb of propellant was estimated. This figure includes raw materials, case preparation and lining, mixing, casting, curing, final assembly, and inspection. Costs for all plants and facilities, motor case and nozzle, and transportation are included in other items in Table **3**.

c. Auxiliary equipment. Auxiliary equipment includes thrust vector control, stage separation, and thrust termination or vernier velocity control systems.

Thrust vector control could be achieved through secondary fluid injection by a simple pressure-feed system. Component development costs for this type of system were computed at $10,000/lb. High-pressure tankage development costs were estimated at $8 million.

Stage separation development, design, and testing would cost approximately $5 million. Vernier velocity control system development would cost $7 million.

Production of high-pressure auxiliary tankage, feed system components, separation devices, etc., costs approximately $200/lb.

d. Guidance, communication, and power. The injection guidance problem was assumed to be equivalent to that for a liquid-propellant rocket vehicle from a cost point of view. The injection vehicle guidance, communication, and power system weight is estimated to be 3,000 lb. Development costs of $30,000/lb and production costs of $1100/lb were assumed. This allows for environmental control and redundancy in accordance with the basic philosophy advocated.

e. Launch operations. To sustain the six-per-year firing rate it is estimated that 1,000 people are required continuously at the launch base. This includes launch pad assembly and firing crew, hangar checkout and assembly crews, and all technical support personnel at the base. The cost of maintaining this force is estimated to be $30 million per year. In addition, transportation of motors from the storage site of the processing plant to the launch pad will cost $350,000 per vehicle (program total of $7 million), and additional launch operations will cost $1 million per vehicle (program total of $20 million). Costs for use of the range are not included.

2. Facilities

General facilities such as engineering space, shops, and laboratories have been included in the development and production cost estimates. Such facilities are provided when (1) sufficient capacity does not exist to meet program needs, (2) existing facilities are not large enough to accommodate the size, or (3) location at some peculiar site is required.

a. Propellant processing facilities. Starting from a totally unprepared site on a waterway, the following facilities are required: case processing, storage and preparation of ammonium perchlorate, storage of other propellant and liner materials, engineering offices, raw material quality control laboratory, mixing and casting of propellant, curing, final motor processing, inspection, storage for enough loaded motors to make two complete vehicles, transport dock and crane, and island development. The cost does not include the purchase of the real estate itself, approximately 60 square miles, since that depends on the final site selection. It does include the complete island (or waterway site) development in the form of land clearing, feeder access roads and utility installation, complete dredging of the internal canals and basins, and all excavation, roadwork, and land preparation.

It is assumed that a processing site can be located sufficiently close to a population center to provide the required work force of approximately 2,500. No costs have been included for housing or support of this work force.

b. Ammonium perchlorate plant. The present national capacity for production of ammonium perchlorate is insufficient to meet the program requirements. This being a captive industry, the cost of a wholly new facility capable of producing 8,000,000 lb per month must be borne by the program.

c. Motor case and nozzle facilities. Because of the large size it is assumed that a motor case and nozzle fabrication and assembly facility must be constructed in its entirety.

d. Launch pad and GSE. Two offshore launch pads with one blockhouse are required at AMR. A breakwater must be provided for each pad. Floating cranes and support ships are used for assembly and launch.

e. Static test facility. No full-scale static structural or dynamic testing is planned on the complete launch vehicle. Adequate facilities already exist for structural static and dynamic testing planned on the subscale models.

Full-scale rocket motor tests of the individual motors will be conducted on the launch pad. Modifications to the pad for this purpose will cost $5 million. A separate static test facility would cost approximately $15 million. Facilities currently exist to handle both motor subscale firing programs.

f. Transportation and storage. The first- and second-stage motor unit creates the major transportation problem. Barge transportation is clearly the only feasible method for empty or loaded motors. It was assumed that the processing plant would be located along the East or Gulf Coasts. Enough barges were included to provide storage between loadings and firings. The case fabrication facility must also be located at a major waterway.

No other elements of the vehicle present any transportation problem of significance.

3. Spacecraft

The spacecraft consists of two major systems: (1) the command and mission module containing the cabin and crew, environmental control, life support, communication, guidance, and reentry equipment and protection, and (2) the lunar landing and return bus which also provides in-course guidance and maneuvers.

Apollo studies conducted by Martin and Convair were used to obtain command and mission module costs. Development costs of $50,000/lb and production costs of $700/lb have been used for the module. The landing/return bus costs were computed at $25,000/lb for development and $350/lb for production, which are typical

costs for the currently envisaged dry-weight bus. These cost estimates cover the spacecraft developer's engineering cost and spacecraft procurement for the *Nova* phase but do not cover the flight test program for spacecraft development, prior to the *Nova* phase.

4. Conclusions

The cost study of the solid propellant *Nova* injection system has revealed some rather unusual, albeit tentative, conclusions. The conclusions reached are a logical consequence of the basic program philosophies.

1. The development costs for this vehicle are considerably lower than for a liquid-propellant vehicle of comparable capability.

2. Production costs per vehicle are roughly comparable to a liquid-propellant vehicle, depending somewhat on the injection mission and the total number of flights.

3. Injection costs in dollars per pound of payload for a 300-mile Earth orbit for a 20-vehicle program are $169/lb total cost and $91/lb production cost. For these computations a reliability of 95% and 515,000 lb of injected weight were used.

4. The development costs are low because the usual full-scale development support programs are not required – no full-scale vehicle structural testing, no captive firings of clusters, no "battleship" propulsion program.

5. Production costs per pound for the structure are low because of the inherent simplicity of a solid-propellant rocket. Size was simply exchanged for complexity at nearly constant total production cost.

F. Growth Potential

The importance and urgency of the manned lunar landing mission obviously focuses attention and major vehicle effort on quickly accomplishing this major-milestone mission. However, in the international space competition, the manned lunar landing and return is merely the first lap in a sustained race. If the nation is to avoid a deficiency in the next "big booster" requirement, some thought must be given to NASA's next major milestone, with a quick look at the following milestones. At any one time, it would seem judicious to have our space plans span at least two major milestones in order that technical and fiscal planning be sound, that continuity be maintained, and that intermediate or minor milestones reinforce one another.

It is assumed that the next major milestone will be a permanent manned lunar laboratory or base and that, in time, this would lead to the next major milestone, man-on-the-planets.

A cargo version of the *Nova* class spacecraft under consideration can place approximately 35,000 lb gross weight on the lunar surface. Such devices as Moon-mobiles, prefabricated structures, and life support systems can be delivered directly from Earth, intact and ready to operate with no assembly or disassembly.

The 25,000,000-lb solid-propellant *Nova* would appear to have considerable growth potential beyond this. Substitution of liquid hydrogen–liquid oxygen stages for the third and fourth solid stages, such that gross weight is unchanged, results in a vehicle that could place approxi-

mately 110,000 lb of men and equipment on the Moon. The first two very large solid-propellant stages would be used as developed for the manned lunar landing and return. The third stage might consist of a cluster of 12 J-2 engines with tankage modified to contain about 1,500,000 lb of propellant (possibly a cluster of three second-stage tanks from the *Saturn C-3*). The fourth stage could be a single S-II stage from the *Saturn C-3*.

This solid–liquid propellant *Nova* vehicle should be capable of placing approximately 930,000 lb into Earth orbit. If one were to use this weight as an electric-powered spacecraft with 50,000 lb of radiation shielding for a 3-man crew using 15 lb/man/day for sustenance, it should be possible to perform a Mars manned landing and return in approximately 590 days.

II. SUMMARY AND CONCLUSIONS

It is appropriate to summarize briefly the preliminary system studies, results, and conclusions and to indicate those steps which should be taken in the near future to assure that system selections made in initiating formal development programs for the manned lunar-landing mission can be made with a maximum degree of confidence.

The solid-propellant launching-vehicle study assumed the use of solid propellant in all stages. Many of the conclusions reached are also applicable to the solid-propellant stages of mixed (solid-propellant and liquid-propellant) systems. The predominant conclusions which have been reached are as follows:

1. A very large, *Nova*, solid-propellant launching vehicle is feasible.

2. The spacecraft-system requirements for either solid or liquid propellant launching vehicles are essentially identical.

3. The injection-guidance requirements for either solid or liquid propellant launching vehicles are essentially identical.

4. Specifying a conservative level of performance for the rocket-motor specific impulse and metal-parts design should, by trading size and weight for time and money, result in an economical program with an early achievement of a useful level of reliability.

5. In these circumstances, the spacecraft development schedule, rather than the launching-vehicle development, would probably become the pacing item in the over-all program.

6. The use of segmented grains is not required for very large solid-propellant motors. The use of maritime equipment and operating techniques avoids this complicating factor. Further study may indicate propellant processing or interior ballistics reasons for preferring a segmented design.

7. The cost and schedule information is based on a minimum development program; the initial conservative specification makes it likely that this result can be more nearly achieved with this system than with systems which require more substantial technological developments.

In addition to the industrial study efforts on the *Apollo* spacecraft now initiated in response to the current RFP, there are activities which would or could help to clarify the over-all system-evaluation problem in the near future.

The advanced-development program for large solid-propellant rockets has resulted in a very successful static test of a 100-in.-diameter segmented design by Aerojet-General Corporation. Additional test firings in this program are scheduled which will provide more information on the development problems associated with large solid-propellant vehicle systems.

In conclusion it must be noted that, in evaluating systems for carrying out the manned lunar-landing mission, attention must be given to the continuing manned space-flight missions which will follow the attainment of the initial goal. At this time, it appears that the continuing manned space-flight program will be associated with the operation of a continuously manned laboratory in a near-Earth orbit, with a similar operation on the lunar surface and, ultimately, with similar operations on the surface of one or more of the other planets or their satellites. The continuing nature of the manned space-flight program does not appear to modify strongly the criteria for selecting the final system, or systems, for implementation of the lunar-landing mission; however, the expected scale of resulting activity has some influence on the over-all criteria.

BIBLIOGRAPHY

1. Ralph M. Parsons Co., Los Angeles, Calif., *Equatorial Orbit Launch Site; Planning Guide*, Eng. File 606-1953, March 1959.

2. Ralph M. Parsons Co., Los Angeles, Calif., *Hawaiian Launching Base*, Eng. File 606-1965, March 1959.

3. Ralph M. Parsons Co., Los Angeles, Calif., *Development Plan, Manus Island*, Eng. File 606-1966, March 1959.

4. Aeronutronic, Newport Beach, Calif., *Acoustical Hazards of Rocket Boosters, Vol. I — Physical Acoustics*, TR U-108:96, November 1960, Contract N123 (61756) 23304A (PMR).

5. Aeronutronic, Newport Beach, Calif., *Acoustical Hazards of Rocket Boosters, Vol. II — Effects on Man*, TR U-108:97, November 1960, Contract N133 (61756) 23304A (PMR).

6. Aeronutronic, Newport Beach, Calif., *Launch Site Criteria for High Thrust Vehicles*, TR U-108:118, March 1961, Contract N123 (61756) 23304A (PMR).

7. National Aeronautics and Space Administration, Langley Research Center, Langley Field, Va., *Near-Field and Far-Field Noise Surveys of Solid-Fuel Rocket Engines for a Range of Nozzle Exit Pressures*, TN D-21, August 1959.

8. *The Design of Two Steam-Electric Plants*, Transactions of the American Society of Civil Engineers, Vol. 121, 1956.

9. U.S. Naval Research Laboratory, Washington, D.C., *Fracture Testing of High-Strength Sheet Materials Under Conditions Appropriate for Stress Analysis*, NRL Report 5486, July 27, 1960.

10. *Fracture Mode Transition for a Crack Traversing a Plate*, Transactions of the American Society of Mechanical Engineers, June 1960.

11. Syracuse University Research Institute, *The Effect of Several Geometrical Variables on the Notch Tensile Strength of 4340 Steel Sheet Heat-Treated to Three Strength Levels*, WADD Technical Report 60-310, September 1960, Contract AF 33(616)-6523.

12. Aerojet-General Corp., Solid Rocket Plant, Sacramento, Calif., *Final Report: Very Large Solid Propellant Rockets for Space Vehicles*, Volume II (Revised), Report 0442-01F-1, May 1961, Contract NAS 5-674.

13. Lockheed Missiles and Space Division, Lockheed Aircraft Corp., Sunnyvale, Calif., *A Study of Large Solid-Propellant Boosters*, December 1959, LMSD-288097, Contract NASw-60.

14. Grand Central Rocket Co., Redlands, Calif., *Final Report: Design Studies of Very Large Solid Fuel Rockets*, GCR F-0036-61, April 9, 1961, Contract NAS 5-672.

15. Space Technology Laboratories, Inc., Los Angeles, Calif., *Interim Progress Report No. 1: Launch Vehicle Size and Cost Analysis*, STL Report 8981-002-NU-000, March 21, 1961, Contract NAS 8-866.

16. United Technology Corp., Sunnyvale, Calif., *Large Solid Rocket Boosters: A Presentation to the Booster Panel of the President's Science Advisory Committee*, May 11, 1961.

17. Thiokol Chemical Corp., Redstone Division, Huntsville, Ala., *Final Report: Design Study of a Solid Propellant Rocket Motor Initial Stage for Very Large Space Vehicles*, Volume I, Report 17-61, March 1961, Contract DA-01-021-506-ORD-787.

18. Aerojet-General Corp., Solid Rocket Plant, Sacramento, Calif., *Final Report: Very Large Solid Propellant Rockets for Space Vehicles*, Volume I, Synopsis of Results (Revised), Report 0442-01F-1, May 1961, Contract NAS 5-674.

19. Thiokol Chemical Corp., Redstone Division, Huntsville, Ala., *Final Report: Design Study of a Solid Propellant Rocket Motor Initial Stage for Very Large Space Vehicles*, Volume II, Report 17-61, March 1961, Contract DA-01-021-506-ORD-787.

20. United Technology Corp., Sunnyvale, Calif., *Feasibility Program for Conical Segmented Rocket Motors*, Proposal 61-07, February 1961, Follow-On Program to Contract NAS 5-273.

21. Aerojet-General Corp., Solid Rocket Plant, Sacramento, Calif., *Segmented Rocket Boosters*, Log 25470.

22. Atlantic Research Corp., Alexandria, Va., *A Proposal for the Development of Low-Cost Reliable Space Vehicle Boosters*, ARC 917, January 12, 1961.

23. Aeronutronic, Newport Beach, Calif., *Final Report: Technical Report Study of Application of Solid Boosters to Space Vehicles*, Publication C-710, December 1, 1959, Contract NASw-43.

24. Atlantic Research Corp., Alexandria, Va., *Investigation and Evaluation of High-Performance Heterogeneous Liquid Monopropellants*, Quarterly Progress Report No. 4, July 1, 1959 to September 30, 1959, Contract 59-6171-c, October 1959.

25. Space Technology Laboratories, Inc., Los Angeles, Calif., *Interim Progress Report No. 1: Launch Vehicle Size and Cost Analysis,* STL Report 8981-0002-NU-000, March 21, 1961. Contract NAS 8-866.

26. Aerojet-General Corp., Solid Rocket Plant, Sacramento, Calif., *Proposal to Jet Propulsion Laboratory for the Development of a High-Performance Solid Rocket Engine for Lunar Spacecraft Propulsion,* SR-61232, June 1961.

27. Jet Propulsion Laboratory, Pasadena, Calif., *Solid Propellant Capabilities for Spacecraft Propulsion,* Technical Report 32-70, April 1961.

28. Martin Aircraft Co., Baltimore, Md., *Apollo Final Report: Business Plan,* ER 12015, June 1961.

29. Convair Astronautics, San Diego, Calif., *Apollo Final Study Report,* Vol. V, Implementation Plan; Book I, Systems Analysis Schedule and Costs, June 1961.

30. Rocketdyne, A Division of North American Aviation, Inc., Canoga Park, Calif., *Interim Report: Propulsion Requirements for Space Missions,* Report ADM 61-66, NASA Contract NAS 5-916, May 31, 1961.

31. Mitchell, David H., "Economics of Booster Vehicle Design," *Ballistic Missile and Space Technology,* Vol. IV, Academic Press, 1960 (p. 377).

32. Space Technology Laboratories, Inglewood, Calif., *Estimating Performance Capabilities of Boost Rockets,* TR 59-792, September 10, 1959.